

0.35 mm long. Carpels c. $\frac{3}{4}$ as long as stamens; ovaries obovoid-cylindrical, abaxially gibbous apically, narrowing rather abruptly into styles only c. 0.2 mm long. Fruit $\pm$ spherical or slightly pyriform, somewhat flattened ventrally, 10–12 mm long, 10–11 mm diameter (9–10 mm dorsiventrally). Epicarp dull purplish-black, finely rugulose. Mesocarp c. 0.4 mm thick, granular, rather dry and oily when fresh. Endocarp bony, rather brittle, straw-coloured, both surfaces smooth but dull. Seed ellipsoid-globose, flattened ventrally, 8–9 mm long, 7–8 mm diameter, surface dark brown. Intrusion penetrating from lateral position for slightly over $\frac{1}{2}$ seed diameter, in l.s. very slightly lobed but not apically dilated, occupying a little over $\frac{1}{2}$ seed length; in t.s. obscurely 2-lobed and slightly dilated, occupying c. $\frac{1}{2}$ seed width. Embryo lateral (c. 3 o'clock relative to stalk). (Fig. 3f, 8b)

Distribution: coastal northeast Queensland, scattered and discontinuous in coastal lowlands from the Kennedy River north-west of Cooktown south to Rollingstone Creek a short way northwest of Townsville, also on Hinchinbrook Island; additionally, I have seen and photographed palms that appear to be of this species around the estuary of the Proserpine River east-south-east of Proserpine, an occurrence separated by $1\frac{1}{2}$ degrees of latitude and 2 degrees of longitude from what is otherwise its southern limit at Rollingstone Creek.

Ecology: chiefly a species of stream banks on flat coastal plains, mainly in bouldery alluvium, apparently confined to streams with a continuous dry-season flow or at least persisting as soaks. It occupies similar habitats above upper limit of mangroves beside sheltered estuaries. It occurs less commonly on hill-slopes, in clay soils on shale or siltstone. The vegetation types in which it occurs range from swamp-forest dominated by *Melaleuca leucadendra* to fringes of gallery-rainforest or tropical rainforest bordering on eucalypt forest dominated by species such as *Eucalyptus tereticornis* and *Corymbia tessellaris*.

Conservation status: 3RC-. This coding is recommended in place of the code 3VC- assigned by Briggs and Leigh (1996) who treated the Cooktown populations as a separate undescribed species with a code 2R (Briggs & Leigh 1996).

Specimens examined: Queensland: Cook: Kennedy River 5.5 km N of New Laura Station, *Irvine* 2204, 26 Nov 1981 (QRS); Kennedy River, *Irvine* 2205, 26 Nov 1981 (QRS); 3.3 km off main road along road at north end of Cooktown Airport, *Hind* 4594, *Hill & Healy*, 3 Aug 1986 (NSW). North Kennedy: North side of Herbert River, at SW base of Mt Leach Range, 14.5 km NW of Ingham, *Rodd* 3135 & *Jacobs*, 17 May 1976 (NSW, BRI, K); at mouth of Herbert River, *Webb & Tracey* 11176, (no date) (BRI); W.J. Huston's property 'Braemeadows' near Ingham, *Thomas s.n.*, 27 Nov 1959 (BRI); Halifax, approx. 2 km along road to Lucinda, *Irvine* 1832, 9 May 1977 (QRS, NSW); Hen Camp Ck, Kinduro, near Bruce Highway, *Irvine* 1833, 1834, 9 May 1977 (QRS, NSW).

Notes

1. This species was known only as a somewhat shadowy entity until Beccari (1931) published an adequate description. In Wendland and Drude's (1875) account of Australian palms a broad concept of *L. inermis* was adopted, and this taxon appears to be the major element in their description. Mueller (1878) recognised this but chose to follow Benthams (1878) who placed tropical Queensland plants of this taxon under *L. australis* without comment. Bailey (1902) followed Benthams treatment.
2. Mueller's epithet appeared only in the index of *Fragmenta* vol. 11, being only implied in the text and associated with *L. australis*, the question of its specific status being left open. Following upon some brief but arguably diagnostic descriptive and distributional comments, Mueller concluded: 'Huic palmae nunc pro speciei vel varietatis distinctione nomen Doctoris Ocaris Drude impono.' It is concluded that this name cannot be regarded as validly published by Mueller.

3. The first subsequent mention of *L. drudei* is in Drude's long but disorganised paper on Australian *Livistona*, in which Mueller's assessment of its status is repeated ('Unterart oder Art?') but without any clear-cut pronouncement based on his own opinion. In his indented key to species Drude relates *L. drudei* to *L. anstralis*. His nesting it under *L. anstralis* without a number of its own suggests that it is given some sort of inferior status; on the other hand non-overlapping distributions are attributed to these taxa, implying separation. I conclude that Drude's (1893) treatment of *L. drudei* is still as a *nomen provisorium* at species rank.

4. The next use of this name is by Beccari, in his synoptical paper of 1921. Here, though the name is attributed to Mueller, it is clearly treated as a species, with an adequate diagnosis in the key. No specimens are designated, but there is a precise reference to Wendland and Drude's misapplied *L. inermis* ('non Rob. Br') as synonym, thus indirectly citing specimens from which the lectotype is here chosen.

5. Jones (1984) draws attention to populations of *Livistona* in Cape York Peninsula, as *Livistona* sp. 'Cooktown'; he cites the localities 'Flinders Island near Bathurst Bay, Kennedy River near Lakefield, tributaries of the Endeavour River and south towards Gap Creek near the Bloomfield River.' The only adequate collections I have seen from any of these localities are *Irvine* 2204 and 2205, both from the Kennedy River. I have examined these carefully and have concluded that these collections fall within the range of variation of *L. drudei*. *Hind* 4594 from near Cooktown consists only of a fallen dead leaf and old infructescence branch but the characters it exhibits all point to it belonging in *L. drudei*.

5. *L. australis* (R. Br.) Mart.

Martius (1838: 241–2); Hooker (1877); Mueller (1878: 55); Bentham (1878: 146); Moore & Betche (1893: 427); Bailey (1902: 1684); Domin (1915: 501); Maiden (1921: 353, t.256); Beccari (1921: 18; 1931: 79–80); Evans & Johnson (1962: 2); Moore (1963: 149; 1965: 148).

Corypha anstralis R. Br., Prodr.: 267 (1810).

Type: New South Wales: Port Jackson, *Brown*; holotype BM; isotype FI, photo NSW.

Trunk solitary, to c. 25 m high, 25–35 (–40?) cm diameter at 1 m above ground, broadening close to ground into a gently flared cone to c. 50 cm diameter, reducing upward for 5–7 m to a final constant diameter of c. 20–25 cm. Surface rough but very regularly patterned, prickly with protruding fibres, with strongly stepped sheath scars; vertical fissures usually closely spaced, often branching, deep and gaping, often with criss-crossing fibres showing within; petiole-stubs absent from adult trunks. *Crown* moderately compact to rather open, ± globose, consisting of 35–60 leaves with straight to gently arching or moderately drooping petioles and pendulous segment-lobes. Ligules moderately prominent, pale brown, patchily floccose with ± appressed scales, margins irregularly fimbriate with fine, soft, straight, tapering scales to 8–10 mm long.

Petiole 140–250 cm long, 10–20 mm wide; t.s. concave-convex to roughly semi-circular, sometimes convex above and often with median ridge (sometimes 2 ridges). Margins unarmed except at base or with a few small, pungent, hooked prickles near apex and scattered minute, blunt teeth elsewhere; toward base armed with ± closely and regularly spaced pungent, mostly retrorsely hooked blackish prickles to 2.5 mm long. Surfaces green, purplish-brown toward base, very finely and shallowly rugulose-striate; upper quite glabrous, sometimes irregularly pitted with narrow, elongated pits, lower rather closely pitted with obscure, shallow, short and broad to long and narrow pits, on young leaves bearing floccose scales to 3–4 mm long, usually pale brown, divided to base into several straplike but usually tightly twisted, branched laciniae; on older leaves usually only numerous minute, whitish to dark

brown pustular, basal-masses with small scale-remnants persisting. *Hastula* cylindrical to flattened; base shortly but broadly 3-lobed, lateral lobes wider than central; rim at 10–90° to costa, 5–30 mm wide usually with blunt peak at centre, with very narrow to broad necrotic margin.

Lamina 110–130 cm long, 0.15–0.25 (mostly 0.18–0.20) mm thick, moderately costapalmate, usually with narrow basal sinus or even with lower edges overlapping, chartaceous-coriaceous, moderately tough to rather brittle and readily split, moderately to strongly contorted with mostly 2 adaxial undulations either side of the moderately deflexed costa and lower edges sometimes involute with lowermost few segments resupinate. **Segments** (35–) 40–46 either side of costa; largest segments 28–49 mm wide, tapering slightly toward point of bifurcation, free for 54–62% of their length, bifurcated for 50–63% of free length, the lobes parallel or slightly diverging, evenly tapering into soft, acute but never aristate or threadlike apices, early-necrotic and frequently broken or split. Intersegmental appendages lacking even on the youngest expanded leaves, or rarely present as remnants to 3 mm long. **Ribs**: abaxial ribs in t.s. elliptic to trapeziform (narrowing to lamina), quite rounded to sharp-edged on one side only, rarely 2-angled though slightly rounded, 0.8–1.3 mm thick, 1.2–2.5 mm deep; adaxial ribs mostly rounded or sharp-edged on one side only, 0.6–0.8 mm thick, 1.4–3.0 mm deep. **Venation**: major longitudinal veins 7–10 either side of abaxial rib, moderately prominent above, slightly less prominent below; transverse veins evident to moderately prominent above, prominent below, fairly crowded, rarely steeply angled, finely sinuous and often also coarsely zigzagging or arcuate, frequently branched, most continuous across $\frac{1}{2}$ – $\frac{3}{4}$ of each half-segment. Surfaces green, glossy, often with strong brownish tinge above, deep green beneath, closely striate between veins, quite glabrous except for ribs minutely punctate with brownish, pustular basal-masses, these stipitate on minute prickles on adaxial ribs close to hastula; on young leaves bearing dense, floccose, pale brownish scales toward bases of ribs.

Inflorescences mostly shorter than petioles, occasionally equalling them. Partial inflorescences 6–9, subequal, the largest slightly over half total inflorescence length but with strongly recurving branches; each branched to 4 (–5) further orders; rachillae 5–25 cm long, 0.7–0.9 mm thick, white when fresh, glabrous, minutely warty, wrinkled-striate when dry. Rachis bracts flattened-cylindrical, 4–5 cm diameter, often rather loose, warped, often wrinkled, very tough, whitish to pale purplish-brown when fresh, drying to deeper chestnut brown; $\pm$ striate, sparsely to densely floccose-scaly, especially toward apex, scales usually pale brown, divided into several twisted, branched laciniae to 7 mm long; bract apices triangular, acute or slightly acuminate. **Flower-clusters** 0.5–3 mm apart, 1–4-flowered; cluster axis 0.5–2.0 (–3.0) mm long, cylindrical, moderately slender; longer cluster axes often with lateral flowers closer to base than apex. Cluster-bract 0.5–1.0 mm long, triangular-ovate, acute or sometimes rather jagged, appressed, membranous except for fleshy base. Bracteoles 1 per flower or sometimes an extra one present on 1-flowered clusters, similar to cluster-bract but shorter, mucronate.

Flowers 2.5–3.5 mm long, broadly funnel-shaped to rotate. Anthopodium 0.2–0.5 mm long, conical to cylindrical sometimes with slight constriction below calyx, minutely recessed at base with 3 obscure basal swellings. Sepals 1.2–2.1 mm long, connate for $\frac{1}{2}$ – $\frac{1}{3}$ their length with very broad shallow sinuses, closely appressed to petals, moderately concave, membranous apically, fairly tough, broadly to narrowly triangular, subacute to acute. Petals 1.8–3.3 mm long, connate for $\frac{1}{10}$ – $\frac{1}{2}$ their length, thick-textured, narrowly triangular to broadly oblong-ovate, bluntly acute to mucronate or almost rounded with thickened, sometimes hooded apex; auriculate at base with distinct retrorse, rounded to angular auricles; inner faces with 3 distinct, broad but rather shallow cavities. Stamens $\frac{1}{2}$ – $\frac{3}{4}$ as long as petals, connate for $\frac{1}{4}$ – $\frac{1}{2}$ their length; filaments thick and fleshy, broadly to narrowly triangular-ovate, hardly

shouldered, tapering smoothly to somewhat abruptly into a slender subulate apex; anthers 0.5–0.7 mm long, the locules narrowly oblong (sterile?) to more broadly oval, often slightly displaced. Carpels $\frac{2}{3}$ – $\frac{3}{4}$ as long as stamens; ovaries cylindrical to ovoid to obovoid and strongly gibbous apically, gradually to abruptly contracting into styles 0.2–0.4 mm long.

Fruit spherical, often slightly flattened ventrally, 13–22 mm diameter; suture often faintly visible; base sometimes extended into a very shallow cone, on stalk to c. 3.4 mm long consisting of thickened cluster axis topped by swollen anthopodium 0.9–1.5 mm long and 1.4–1.8 mm diameter. Epicarp deep reddish-brown to black, or black with brownish ‘cheek’, dull or with subdued satiny sheen, minutely verruculose and with sparsely and irregularly scattered pale brown circular spots 0.2–0.8 mm diameter often with central pore. Mesocarp 2–3 mm thick, olive green, firmly fleshy and hardly juicy when fresh; when dry granular with reddish-brown tannin-bodies, sparse thin fibres present, sometimes only adjacent to endocarp. Endocarp 0.2–0.3 mm thick, straw-coloured to pale brown, flexible but rather weak, mostly adhering to mesocarp; both inner and outer surfaces smooth but very minutely rough with loose spicular or papillose surface cells. **Seed** 11–16 mm diameter; surface pale brown, minutely rough and porous. Intrusion penetrating diagonally from sub-basal position for $\frac{1}{2}$ – $\frac{3}{4}$ seed diameter, in l.s. $\pm$ oblong with broadly flared base, and rounded to shallowly 2-lobed summit, occupying $\frac{1}{3}$ – $\frac{1}{2}$ seed length; in t.s. similar but less flared at base, occupying c. $\frac{2}{3}$ seed width. Embryo sub-basal, (4 to 5 o’clock relative to stalk). (Fig. 3g, 8c, 10)

Distribution: coastal eastern Australia south of 19° lat. It extends southward from about the upper Noosa River (E of Gympie) in Queensland more or less continuously through New South Wales to near Batemans Bay but thereafter shows increasingly wide disjunctions until its last outpost in far eastern Victoria, close to the Snowy River mouth (see Note 6 below). Furthest inland occurrences observed are about 100 km from the sea in the upper Richmond and Clarence River basins, this distance diminishing southward, and at altitudes not exceeding about 500 metres. North of the Noosa River it is known from one small stand on Fraser Island (the common species on Fraser Island is *L. decipiens*), and thereafter only as widely disjunct occurrences in the Eungella–Crediton area near Mackay, and the southern Paluma Range–Keelbottom Creek area northwest of Townsville. Stands of palms which may well belong to this species have been sighted near the summit of Mt Elliot just south of Townsville, on Mt Dryander north of Proserpine, and on Mt Aberdeen west of Bowen. All these occurrences north of the Tropic are at altitudes between 500 and 1000 metres.

Ecology: occurs in a wide range of forest types, but most commonly in swamp-forest associated with species such as *Melaleuca quinquenervia* and *Eucalyptus robusta*, rainforest margins, or gallery-rainforest. In such wet situations it appears to be indifferent to soil type. Also found frequently on exposed slopes above the sea, principally on exposures of softer sediments, e.g. the Narrabeen Series close to Sydney, sometimes locally dominant on such sites. In some near-coastal areas it is common on valley-slopes in tall wet sclerophyll forest dominated by, e.g., *Eucalyptus saligna* and *Syncarpia glomulifera*, but is absent from such forests over wide regions. It is absent from all the ‘rain shadow’ reaches of coastal valleys such as those of the Hunter and Hawkesbury Rivers, though this may be due to incidence of destructive floods rather than insufficient moisture; isolated stands often occur in nearby tributary valleys in the mountain escarpment.

Conservation status: not considered at risk. Eungella and Paluma populations were listed as *Livistona* sp. 5 and sp. 6 respectively by Briggs and Leigh (1996) and given conservation codes of 2RC- but I consider these to be part of this widespread and abundant species (see note 4 below).

Specimens examined: Queensland: North Kennedy: Paluma Range, Dotswood Holdings, 22 km west of Bluewater Creek on Forestry Road, *Irvine* 1928, 1929, 1930, 28 Jun 1979 (QRS, NSW); Bluewater Creek Forest Road about 22 km SW of Bruce Highway, *Rodd* 3758 & *Lavarack*, 24 Nov 1981 (NSW). South Kennedy: c. 2 km SE of Eungella on Broken River Road, *Rodd* 3073 & *Jacobs*, 13 May 1976 (NSW). Wide Bay: Fraser Island, on margins of rainforest inland from Happy Valley on eastern side of island, *Baxter* 901, 4 May 1967 (BRI); 13 km E of Cooroy on Tewantin road, *Rodd* 3030 & *Jacobs*, 6 May 1976 (NSW, BRI); about 4.8 km N of Nambour, *Moriarty* 671, 672, Aug 1971 (BRI). Moreton: Mooloolaba, c. 70 miles [113 km] N of Brisbane, *Moore* 9229 & *Everist*, 9 Feb 1964 (BRI, BH?); between Mt Glorious and Mt Nebo, *Blake* 21484, 15 Apr 1961 (BRI).

New South Wales: North Coast: Seal Rocks, 20 miles [32 km] E of Bulahdelah, *Briggs s.n.*, 1 Aug 1964 (NSW); N of Ferny Creek, NW of 'Hut', W of Wallis Creek, *Salasoo* 3322, 6 Jan 1967 (NSW). Central Coast: 'Warra' (Univ. of Sydney Biological Field Station), Pearl Beach, *Rodd* 2672, 17 Jul 1974 (NSW); Bayview, Cabbage Tree Road, just inside W edge of golf course, *Rodd* 3615, 12 Dec 1980 (NSW); McCarrs Creek, Kuring-Gai National Park, *Rodd* 2671, 17 Jun 1974 (NSW); Kurnell, Botany Bay, *Boorman s.n.*, May 1906 (NSW); above Garie Beach, Royal National Park, *Rodd s.n.*, 28 Aug 1975 (NSW, QRS); Upper Kangaroo Valley, *Rodd* 2398, 27 Aug 1973 (NSW); Mt Cambewarra NW of Nowra, *Constable s.n.*, 7 Dec 1950 (NSW). South Coast: 13 km from West Bodalla, *Evans* 96, 23 Jul 1976 (NSW); Tanja, on coast ENE of Bega, *per Glenfield Vet. Res. Station, s.n.*, Jul 1954 (NSW); New Holland, *Banks & Solander* 1770 Fl n.v. photo NSW.

Victoria: Cabbage Tree Creek, *Webb* CBG 010319, 9 Mar 1965 (NSW).

Notes

1. This is the only *Livistona* occurring naturally south of 26° latitude (except perhaps for *L. decipiens* and *L. nitida* whose southern limits are both very close to this parallel). Its southern limit at lat. 37° 45' in eastern Victoria makes it the second most southerly palm in the world after the New Zealand *Rhopalostylis sapida*.
2. A common species in the Sydney area, it is abundant on the south shore of Botany Bay, and was collected by Banks and Solander when Cook's first voyage reached this, its first Australian landfall, in 1770. No palm, though, is illustrated or even mentioned in the 'Illustrations of the Botany of Cook's Voyage Round the World', which suggests that even these intrepid botanists and their artist, Parkinson, gave little attention to such massive plants. However, there are specimens in BM and FI and a manuscript of Solander's in the British Museum (a copy of a page of which was kindly shown me by Mr D. McGillivray), summarising the species to be included in his never-completed manuscript flora. The names in it are mere provisional tags; four apparent palm names are listed, one being *Corypha nuda* from Botany Bay. It is likewise strange that no subsequent mention of this palm appeared in botanical or horticultural literature until Brown's 'Prodromus' was published in 1810.
3. Another puzzle is Brown's attribution of this species to the genus *Corypha* L., while at the same time erecting the new genus *Livistona* for *L. inermis* and *L. humilis*. The characters by which he differentiates these genera are very slight, amounting to little more than a small shift in embryo position. Brown was surely aware of Linnaeus's *Corypha umbraculifera* being typified (primarily) by Rheede's *Codda-pana* with its striking terminal inflorescence, but he may have preferred to characterise it by its other element, Rumphius's *Saribus*, which is the species now called *Livistona rotundifolia*. Against the latter interpretation is the separation by Lamarck in 1786 of the latter element as a distinct species, *C. rotundifolia*, in effect narrowing the application of Linnaeus's name to 'Codda-pana'. Brown's separation of the two tropical Australian species under a new genus (*Livistona*) was probably influenced by their different growth-habit and ellipsoid fruits, but these characters are not part of his generic diagnosis.
4. Jones (1984), quoting the observations and collections of A.K. Irvine, distinguished *L. sp.* 'Eungella Range' and *L. sp.* 'Paluma Range'. These were characterised as follows:

$1 \times 10^{-7} \text{ g cm}^{-2} \text{ min}^{-1}$ is generally considered adequate for plant growth (Gradwell, 1972). The purely inorganic soil matrix supplemented with inorganic fertilizer had the advantage of not inducing the type of reducing conditions as might be encountered when digested sludge was incorporated in clay soils.

Figure 1 presents pF plots of the average water contents of cores from the compacted clay loam soil after equilibration at five values of moisture tension. Under the weak compaction exerted by finger pressure or rubber hammer, the soil had about 10% more water available at tensions of 10 and 25 cm than in soils compacted by steel bar or by machine compression. At high moisture tensions, above 75 cm, the water contents of the cores were similar for all methods of compaction. Mixing sand with the clay loam had marked influence on the water content of the cores after equilibration at different moisture tensions. Figure 2 shows pF curves of water content against moisture tension for mixtures of clay loam and sand, and clay loam and sludge, when all were compacted with the steel bar. The water contents were all very similar at low moisture tensions. At high moisture tensions, the water contents varied inversely according to the amount of sand that had been added. In other words, addition of sand made water more easily available.

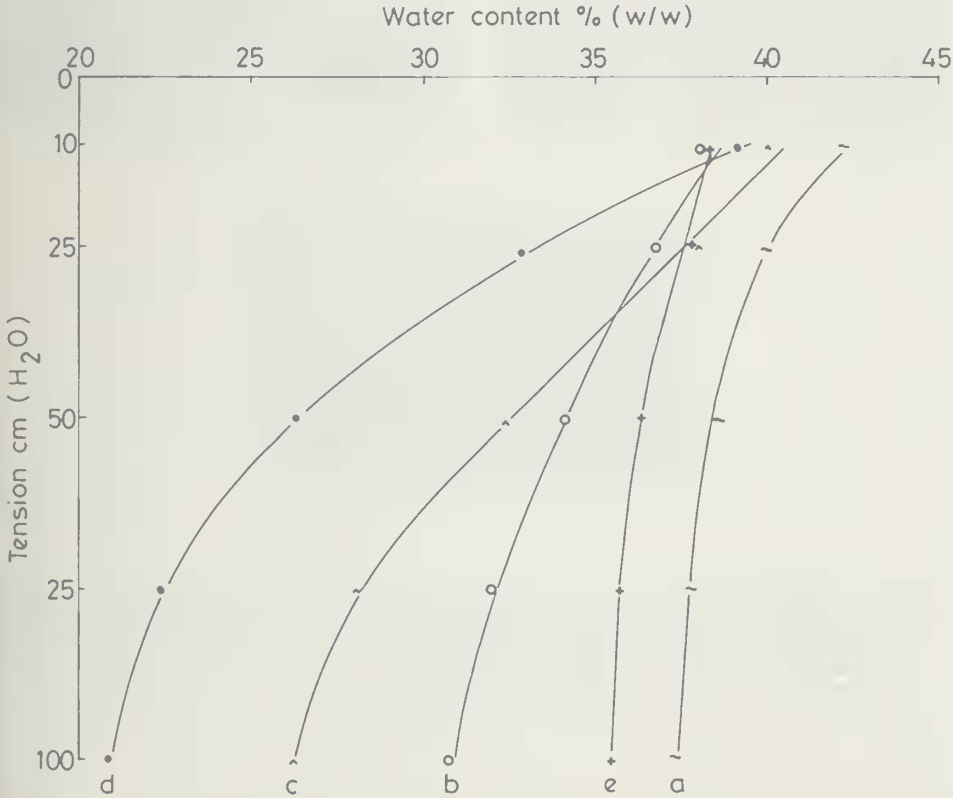


Fig. 2 Water contents of a clay loam ameliorated by sand or sludge and compacted with a steel bar. Composition: a, clay loam; b, 80% clay loam + 20% medium sand; c, 50% clay loam + 50% medium sand; d, medium sand; e, 80% clay loam + 20% sludge. Note. Each point on the graphs is an average of 2 measurements.

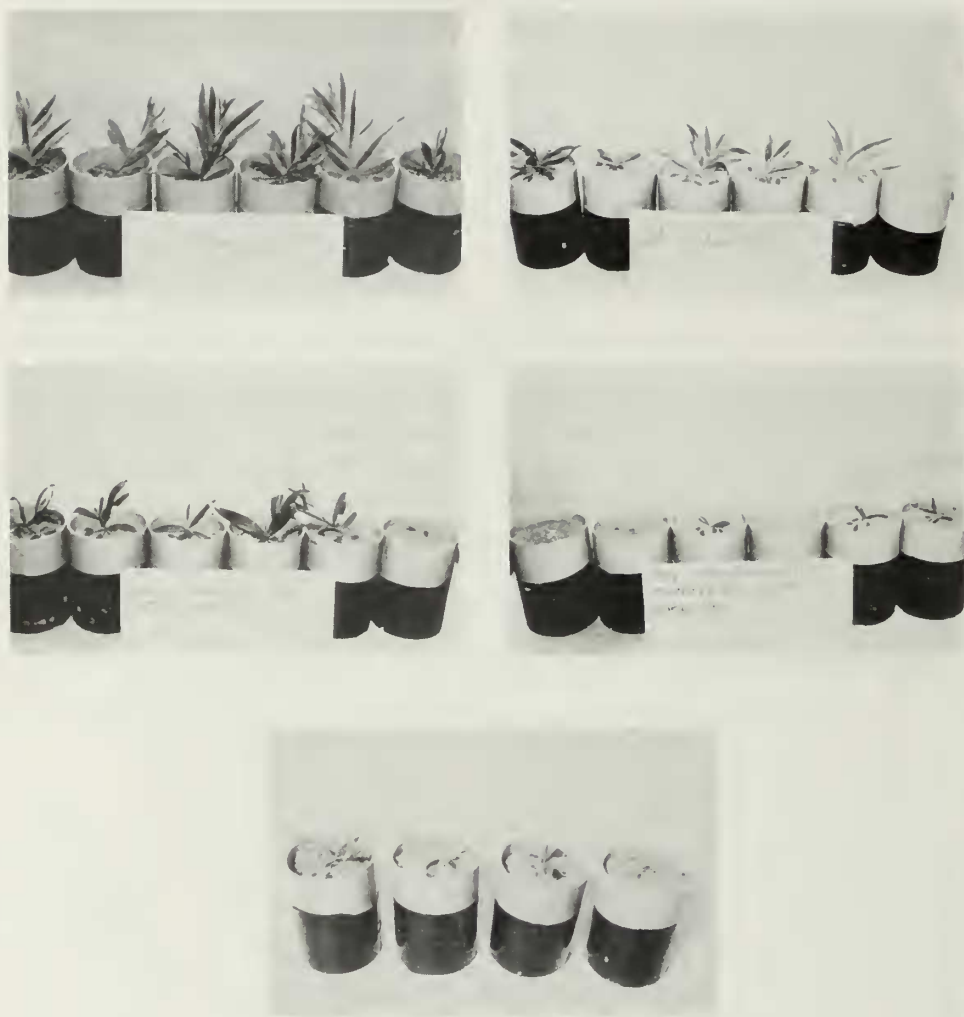


Plate 3. Development of plant top on clay loam under different levels of compaction.

A, above left, treatment 1; *B*, right, treatment 2; *C*, middle left, treatment 3; *D*, right, treatment 4; *E*, below, comparison of 4 rates of compaction on the development of plant top; left to right, treatment 1 (control), treatments 2, 3 and 4.

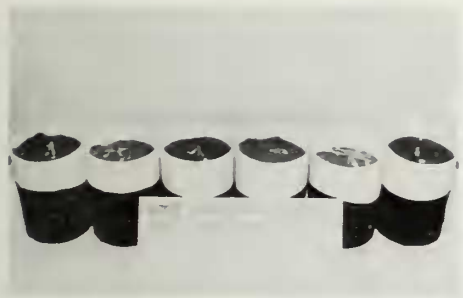


Plate 4. Development of plant top on clay loam amended with 2 rates of sand, pure sand and clay amended with sludge, all compacted with steel bar.
A, above left, treatment 6; *B*, right, treatment 7; *C*, middle left, treatment 5; *D*, right, treatment 8; *E*, below, comparison of the ameliorative effects of 2 rates of sand on the development of plant top; left to right, treatment 1 (control), treatments 6, 7, and 5.

Conclusions

A. pycnantha seedlings were unable to establish roots on a scarified surface of a pan material from the subsoil of Paremata clay or on the remoulded pan material containing adequate mineral fertilizer.

It was evident that upon compaction, soil strength became the severely limiting physical attribute that controlled the establishment and early growth of *A. pycnantha* in the Paremata clay-loam subsoil. A direct relationship was found between this property and the degree of compaction. Mechanical impedance, derived from machine compaction, represented a limit to penetration by roots. Hence, the growth of *A. pycnantha*, a very hardy plant, could be inimically affected by high degrees of soil compaction.

Alleviation of the dramatic changes in soil strength due to compaction was accomplished by adding a medium-size grade of sand on a 50%V basis prior to compaction; this resulted in normal plant growth.

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Literature Cited

- Audus, J. W. (1934). *Native trees of Australia*, 84. Whitcomb & Tombs Limited, Australia.
- Baligar, V. C., V. E. Nash, F. D. Whisler & D. L. Myhre (1981). Sorghum and soybean growth as influenced by synthetic pans. Communications. *In Soil Sci. Plant Anal.* 12: 97-107.
- Barley, K. P. & E. L. Greacen (1967). Mechanical resistance as a soil factor influencing the growth of roots and underground shoots. *Advan. Agron.* 19: 1-43.
- Boone, F. R., J. Bouma, & L. A. H. de Smet (1978). A case study on the effect of soil compaction on potato growth in a loamy sand soil. 1. Physical measurements and rooting patterns. *Neth. J. agric. Sci.* 26: 405-420.
- Cannell, R. Q. (1977). Soil aeration and compaction in relation to root growth and soil management. *In* T. H. Coaker (ed.), *Applied Biology* Vol. 11, 1-86. Academic Press, London.
- . (1982). Cereal root systems: Factors affecting their growth and function. *Monograph, British Plant Growth Regulator Group*, No. 7, 118-129.
- Drew, M. C. & M. J. Goss (1973). Effect of soil physical factors on root growth. *Chemistry & Industry* 21: 679-684.

- . (1974). Environmental stress and the growth of barley root systems: the effect of nutrient ion concentration and mechanical impedance. In R. L. Bielecki, A. R. Ferguson & M. M. Cresswell (eds.), *Mechanisms of regulation of plant growth*, 111-119. The Royal Society of New Zealand, Wellington.
- Eavis, B. W. (1972a). Soil physical conditions affecting seedling root growth I. Mechanical impedance, aeration and moisture availability as influenced by bulk density and moisture levels in a sandy loam soil. *Pl. Soil* 36: 613-622.
- . (1972b). Soil physical conditions affecting seedling root growth. II. Comparisons between root growth in poorly aerated soil and at different oxygen partial pressure. *Pl. Soil* 37: 151-158.
- Gradwell, M. W. (1972). Methods for physical analysis of soils. *New Zealand Soil Bureau Scientific Report* 10c.
- Greacen, E. L. & R. Sands (1980). Compaction of forest soils. *Aust. J. Soil Res.* 18: 163-189.
- Heilman, P. (1981). Root penetration of Douglas-fir seedlings into compacted soil. *Forest Sci.* 27: 660-666.
- Lal, R. & D. J. Greenland (eds.) (1970). *Soil physical properties and crop production in the tropics*. John Wiley & Sons, New York.
- Mitchell, M. L., A. E. Hassan, C. B. Davey & J. D. Gregory (1981). Effect of soil compaction on root development and seedling establishment. *American Society of Agricultural Engineers, Paper No.* 81-1040.
- New Zealand Soil Bureau (1968). Soils of New Zealand. Part 3. *New Zealand Soil Bureau Bulletin* 26: 127.
- Raghavan, G. S. V., F. Taylor, B. Vigier, L. Gauthier, & E. McKyes (1982). Effect of compaction and root rot disease on development and yield of peas. *Can. Agric. Eng.* 24: 31-34.
- Ruark, G. A., D. L. Mader & T. A. Tattar (1982). The influence of soil compaction and aeration on the root growth and vigour of trees — A literature review. Part 1. *Arboriculture Journal* 6: 251-265.
- Russell, R. S. & M. J. Goss (1974). Physical aspects of soil fertility — The response of roots to mechanical impedance. *Neth. J. agric. Sci.* 22: 305-318.
- Sands, R. & G. D. Bowen (1978). Compaction of sandy soils in Radiata Pine forests. II. Effects of compaction on root configuration and growth of Radiata Pine seedlings. *Aust. For. Res.* 8: 163-170.
- Vigier, B., G. S. V. Raghavan & G. Drake (1983). Effect of soil compaction and sterilization on root rot disease and yield of canning peas. *Can. J. Plant Sci.* 63: 327-331.
- Zisa, R. P., H. G. Halverson & B. B. Stout (1980). Establishment and early growth of conifers on compact soils in urban areas. *Forest Service Research Paper* NE-451. USDA Forest Service Northeastern Forest Experiment Station.